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How many damaged corals in Red Sea reef systems? A quantitative survey

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Abstract

Quantitative coral damage assessment by means of line transects was performed in several northern Red Sea coral reef sites in Israel (Eilat) and Egypt (Hurghada area). Reefs with high and low visitor frequency were compared. For both reef systems, breakage was found to be the most common damage category, being significantly higher on highly frequented reefs. Also, all observed damage (breakage, tissue loss, algal overgrowth) was most frequent within the first ten meters depth. A significant difference in the amount of corals overgrown by algae was found on the reefs near Hurghada as compared to all other reefs. Algal overgrowth was correlated with the occurrence of tissue loss and breakage, being considered as a consequence of pollution or the former damage types. In all cases of damage, *Acropora* was the most frequently affected genus, while *Millepora dichotoma* was the most affected species.

Introduction

This study deals with the classification and quantification of damage of scleractinian corals in a number of Red Sea reefs in Eilat (Israel) and Hurghada (Egypt). Both localities are subject to human-induced stress due to water-based tourism activities and pollution. The effects of pollutants on different coral species are often difficult to assess (Mitchell & Chet, 1975; Walker & Ormond, 1982), and long-term investigations are necessary for quantification (Rinkevich & Loya, 1977). The effects of mechanical stress, such as breakage or turning over of colonies, are easier to quantify and can be recorded by means of line transects (Antonius & Weiner, 1982). With this method, various degrees of algal overgrowth on corals, tissue loss or death of a colony can also be recorded. We have compared the amount and quality of damage in fringing reefs which are under urban influence, or sites often frequented by tourists, with reefs located offshore or poorly frequented. Hence an attempt is made to detect characteristic damage features and patterns, to differentiate between natural and human-induced damage causes.

Study sites

Quantitative coral community structure and damage were assessed at 9 localities, one in Israel and 8 in Egypt (Fig. 1).

In Israel, data were collected on the mainland fringing reef within the nature reserve at Eilat in the north-western Gulf of Aqaba. Eilat is one of

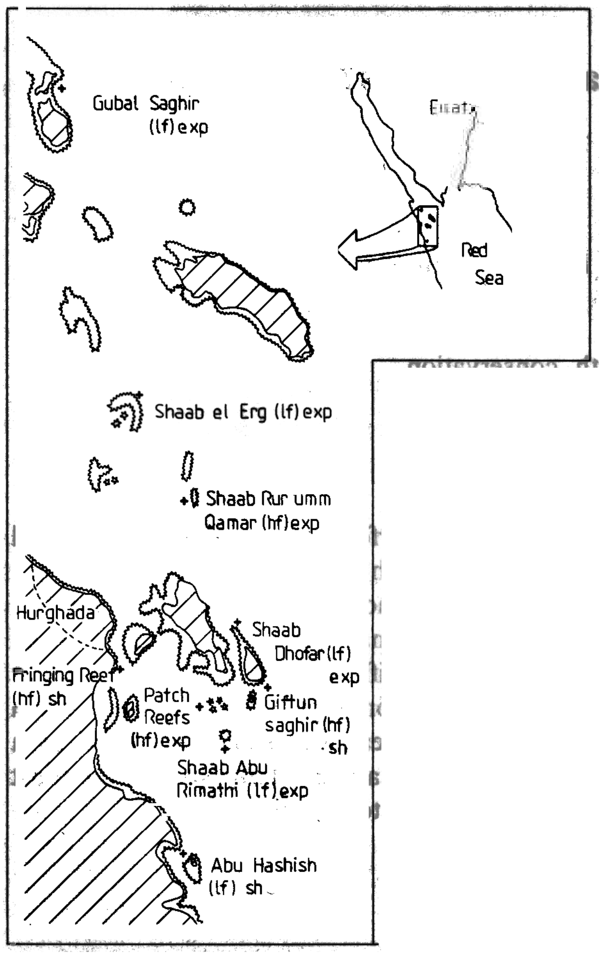

Fig. 1. Map of the northern Red Sea depicting the studied sites in Israel and Egypt. lf = low visitor frequency; hf = high visitor frequency; exp = exposed; sh = sheltered.

the region's biggest tourist centers and the coral reef reserve is an important and heavily used attraction for water-based tourist activities.

In Egypt, several sites were chosen, ranging from the little-used reefs in the Straits of Gubal to heavily used reefs in the Hurghada area. Hurghada is one of Egypt's main tourist centers with mainly water-based activities. We sampled one mainland fringing reef at Hurghada; island fringing reefs at Gubal saghir and Giftun saghir (leeward reef and windward reef, here called Shaab Dhofar); and at Abut Hashish, several patch reefs south of Giftun kebir island and the platform reefs Shaab el Erg, Shaab Rur umm Qamar and Shaab Abut Rimathi. These can be divided into reefs with high and low visitor frequency (Fig. 1). The division is based on the assumption that the former reefs (Giftun saghir, Patch reefs, Shaab Rur umm Qamar) are close to Hurghada and can be reached by boats even in adverse wind and wave conditions. This is not the case with Shaab Dhofar, Gubal saghir, Shaab el Erg, Shaab Abu Rimathi and Abu Hashish which are further away and unsuitable for anchoring in stormy seas.

Material and methods

Data were collected using the line transect method (Loya, 1972; 1978). A minimum of one 10 m transect per meter depth was surveyed per reef. In the Egyptian localities, work was concentrated on the reef slope due to the large number of reefs surveyed. The reef flats and fore reef areas were sampled only on selected reefs (Giftun saghir, Gubal saghir, Shaab Dhofar, Abu Hashish): 143 transects in Egypt and 88 transects in Israel were surveyed.

All scleractinian coral colonies were examined for damage (Antonius & Weiner, 1982) and listed under the following categories. 1) Breakage: describing colonies which were alive but broken or overturned. Colonies were classified as broken when any part of the colony was damaged or removed by breakage and no extensive regeneration or callus formation (Müller *et al.*, 1983) had taken place. Non-attached but otherwise healthy colonies were classified as broken if there was visible evidence that the stem had been broken off. 2) Tissue loss: divided into two sub-categories, viz, minor tissue loss, if less than half of a colony's original tissue area had recently been lost (the originally tissue-covered skeletal area can be identified since freshly stripped areas appear shining white or with a greenish hue (Antonius, 1985) and still exhibit all fine coenosteum and calicular structures); major tissue loss, if a coral colony had lost more than half of the originally tissue-covered area. 3) Algal overgrowth: if any part, which could be tissue-covered or not, of the live colony showed a macroscopically visible overgrowth of algae.

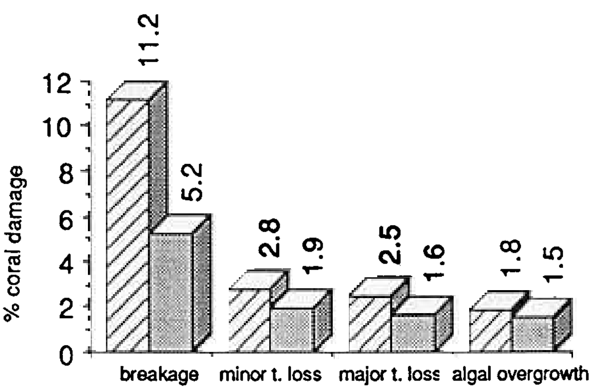

Fig. 2. Overall damage values (in %) for Israel and for pooled data from all Egyptian reefs. Hatched bars = values from Israel; dotted bars = values from Egypt; t. loss = tissue loss.

Results

In this survey the hydrozoon *Millipora* was grouped with the scleractinians, of which 1544 colonies were surveyed in Israel and 2083 colonies in Egypt. The following overall damage patterns were observed (Figs 2, 3). In both countries breakage was the most frequent damage category. The damage extent on the Eilat reef was similar to the Egyptian reefs with high visitor frequency (Fig. 3). When considering pooled values from Israeli and Egyptian reefs, the species with the highest damage frequency was *Millepora dichotoma*. We recorded 75 damaged hydrocorals, representing 28.8% of the *M. dichotoma* colonies on the transects.

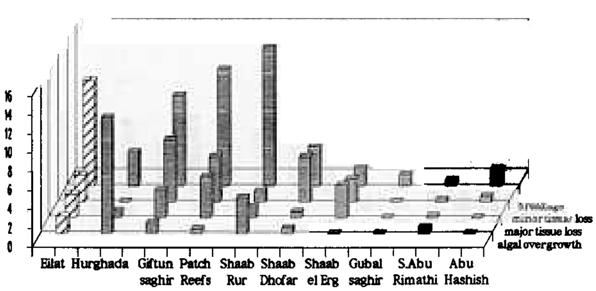

Fig. 3. Damage values (in %) from reefs with high visitor frequency (Eilat, Hurghada, Giftun saghir, Patch Reefs, Shaab Rur umm Qamar) and reefs with low visitor frequency (Shaab Dhofar, Shaab el Erg, Gubal saghir, Shaab Abut Rimathi, Abu Hashish).

The highest percentages of damaged coral species in Israel were *Acropora squarrosa* (51.1%), *Stylophora pistillata* (40.9%), *Acropora hemprichi* (37.8%) and *Millepora dichotoma* (28.9%). In Egypt they were *Acropora hyacinthus* (31.5%), *Millepora dichotoma* (27.5%), *Acropora valida* (15.5%) and *Pocillopora damicornis* (22.3%).

Breakage

Israel: 173 colonies (11.2%), Egypt: 108 colonies (5.2%) (Fig. 3). In both countries significantly more corals were broken within the first 10 m depth than in the grouped depth ranges 10–20 m and 20–30 m (Israel: $\chi^2 = 273.7$, 2 d.f., $p < 0.001$; Egypt: $\chi^2 = 66.5$, 2 d.f., $p < 0.001$). In Israel 50% of all broken colonies were observed within the shallowest 2 m and 84% in < 10 m. The *Millepora* Zone (Loya, 1972), situated at the reef edge between 0.5 and 2 m depth, showed the highest breakage values (14% of all corals).

In Egypt 42.7% of all breakage was found within the first 10 m depth, 22.5% in depths < 5 m. The reef crest transects contributed 8.6% of breakage, while the reef slope transects contributed 32.3%. Significantly fewer corals ($t = 6.2$, 30 d.f., $p < 0.001$) were broken on exposed reefs with low visitor frequency (Shaab el Erg, Gubal saghir, Shaab Dhofar, Shaab Abu Rimathi) than on less exposed reefs with high visitor frequency (Giftun saghir, Patch Reefs, Shaab Rur umm Qamar).

In Israel the most frequently broken species (Fig. 4a) were *Millepora dichotoma* (21.4% of total breakage values), *Stylophora pistillata* (20.8%) and *Acropora hemprichi* (17.3%). These 3 species dominate the coral communities in the upper 10 m of the reef (Loya, 1972). In both countries *Acropora* was the most frequently broken genus (Israel 49.7%, Egypt 42.3% of total breakage). The most frequently broken corals in Egypt (Fig. 4b) were *Millepora dichotoma* (34.4% of total broken occurrences), *Acropora hyacinthus* (22.2%) and *Acropora valida* (15.7%). These species are dominant on shallow exposed to semi-exposed reef flats and reef edges (Riegl, 1989).

Minor tissue loss

Israel: 43 colonies (2.8%), Egypt: 40 colonies (1.9%) In Israel the highest occurrence values were observed at depths between 4 and 5 m. In the first 10 m significantly more ($\chi^2 = 62.6$, 2 d.f., $p < 0.001$) colonies were affected than in the depth zones 10–20 m and 20–30 m. Similar results were obtained in Egypt ($\chi^2 = 31.0$, 2 d.f., $p < 0.001$).

There were highly significant differences in the frequency of minor tissue loss between reefs with high and low visitor frequencies ($t = 5.1$, 17 d.f., $p < 0.001$). The affected species are given in Fig. 5a, b for all localities. In Egypt the contribution of *Acropora* species alone amounted to 40% of all colonies exhibiting partial tissue loss.

Major tissue loss

Israel: 38 colonies (2.5%), Egypt: 33 colonies (1.6%). In Israel highest values were observed in the upper fore reef area (38 colonies = 31.5%). In both countries significantly more corals were damaged within the first 10 m depth than between 10–20 m and 20–30 m (Israel: $\chi^2 = 30.2$, 2 d.f., $p < 0.001$, Egypt: $\chi^2 = 25.9$, 2 d.f., $p < 0.001$). In contrast to the observed minor tissue loss no significant difference in the frequency of major tissue loss was found between reefs with high and low visitor frequency ($t = 0.001$, 12 d.f., $p > 0.05$). Pooled values from major and minor tissue loss gave a significant difference ($t = 2.7$, 30 d.f., $p < 0.01$) between the two reef groups. Again *Acropora* was the most frequently damaged genus (in Egypt) contributing 60.8% of damaged colonies (Fig. 6a, b).

Algal overgrowth

Israel: on 28 colonies (1.8%), Egypt: on 31 colonies (1.5%). In both countries significantly more coral colonies were affected within the first 10 m depth than between 10–20 m and 20–30 m (Israel: $\chi^2 = 14.6$, 2 d.f., $p < 0.01$, Egypt: $\chi^2 = 30.24$, 2 d.f., $p < 0.001$). In Israel the highest occurrence of algal overgrowth was observed on the reef flat (28 colonies or 50% of total occurrence). In Egypt most algal overgrowth (67.7%) was observed at depths of < 1 m (reef flats and Hurghada fringing reef transects), and at about 15 m average depth (16.1%, lower reef slope and fore reef transects).

In Israel the frequency of algal overgrowth showed low correlation ($r = 0.44$, $n = 6$, $cov = 23.6$) with the frequency of breakage, very high correlation with the frequency of minor tissue loss ($r = 0.92$, $n = 6$, $cov = 42.4$) and moderate correlation with major tissue loss ($r = 0.70$, $n = 6$, $cov = 14.1$); whereas in Egypt there was high correlation with the frequency of breakage ($r = 0.76$, $n = 6$, $cov = 104.4$) and minor tissue loss

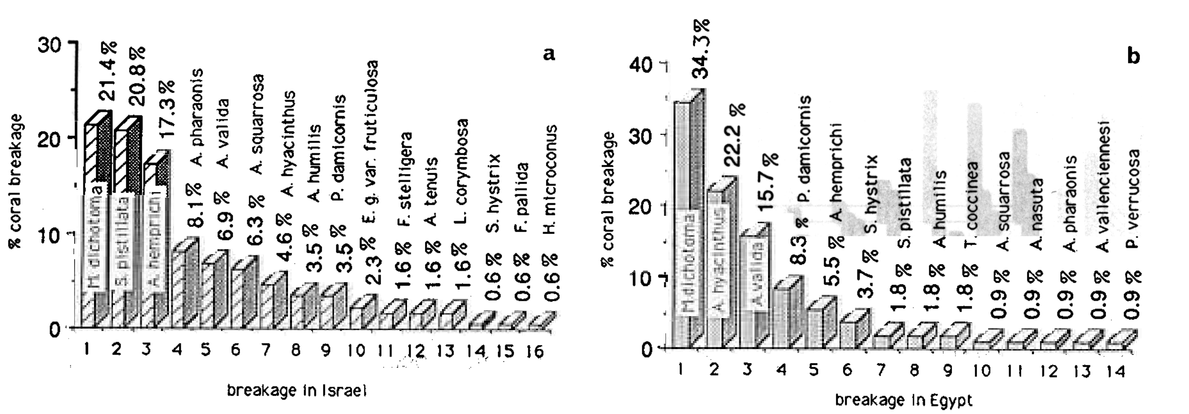

Fig. 4. Percentage of individual species contribution to total breakage in Israel (a) and Egypt (b) (pooled values from all reefs). E.g. = *Echinopora gemmacea*.

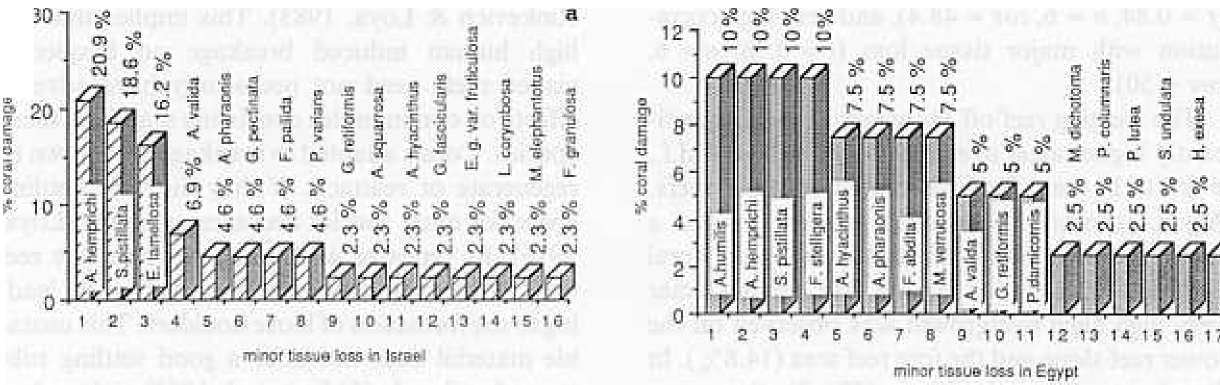

Fig. 5. Percentage of individual species contribution to total minor tissue loss in Israel (a) and Egypt (b) (pooled values from all reefs).

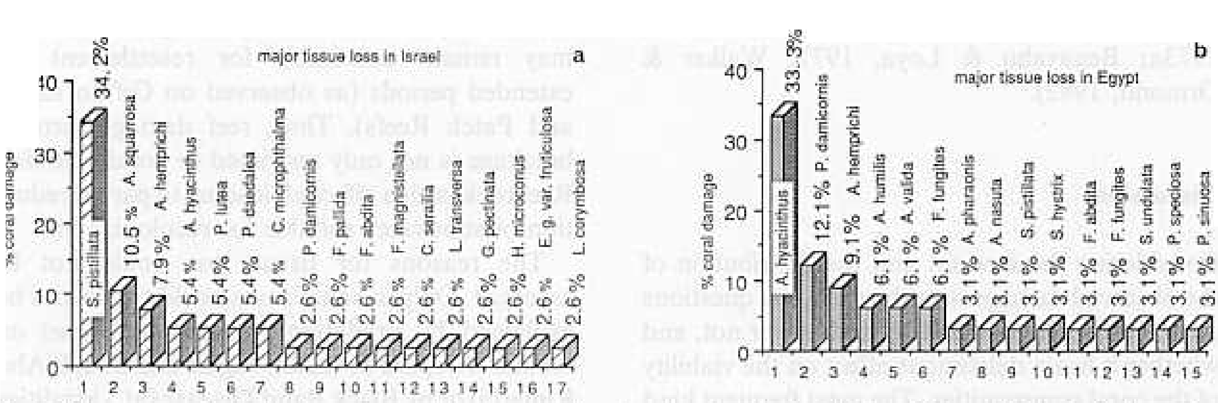

Fig. 6. Percentage of individual species contribution to total major tissue loss in Israel (a) and Egypt (b) (pooled values from all reefs).

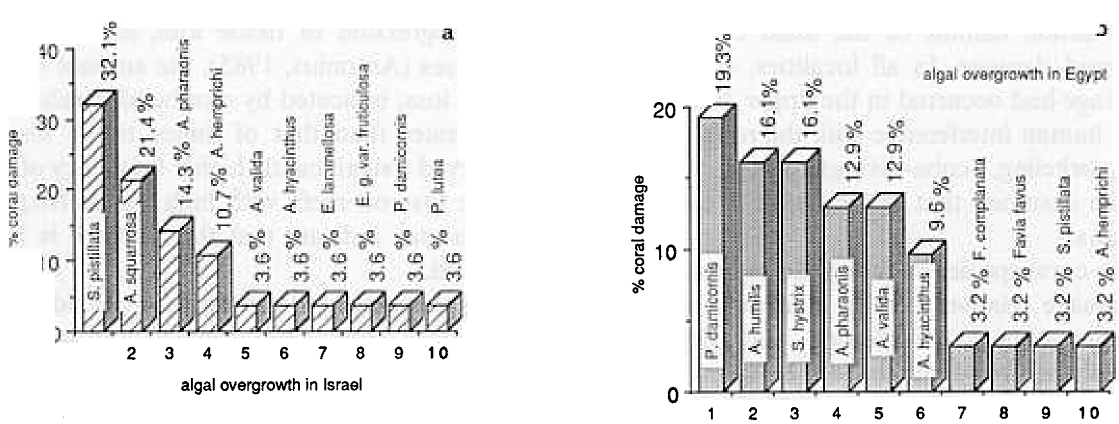

Fig. 7. Percentage of individual species contribution to total algal overgrowth on living and dead corals in Israel (a) and Egypt (b) (pooled values from all reefs).

($r = 0.84$, $n = 6$, $cov = 48.4$), and very high correlation with major tissue loss ($r = 0.96$, $n = 6$, $cov = 50$).

The fringing reef off Hurghada showed significantly higher algal overgrowth ($\chi^2 = 29.4$, 4 d.f., $p < 0.001$) than the investigated offshore reefs. Algae, especially *Colpomenia sinuosa*, formed a dense coverage on all substrates and many coral colonies (12.3%). At Shaab Rur umm Qamar very high algal overgrowth was observed on the lower reef slope and the fore reef area (14.8%). In Israel, as well as in Egypt (Fig. 7), the genus *Acropora* was most affected (Israel: 53.6%, Egypt: 54.8% of total values). The algae mostly belong to the filamentous genera *Ectocarpus*, *Dichotrix*, *Enteromorpha* and the non-filamentous *Hydroclathrus*, *Ulva* and *Colpomenia* (Fishelson, 1973a; Benayahu & Loya, 1977; Walker & Ormond, 1982).

Discussion

Considering the amount and the distribution of the observed damage over the reefs, the questions arise whether it is caused by humans or not, and whether it has a deleterious effect on the viability of the coral communities. The most frequent kind of damage observed in Israel and Egypt was breakage. Exposed reefs with low visitor frequency showed significantly fewer broken corals than the less or equally exposed reefs with higher visitor frequency. Therefore, breakage due to wave action cannot be the main cause of the observed damage. In all localities, most of the breakage had occurred in the upper 10 m, where most human interference with the reefs (anchoring, snorkeling, Scuba-diving) takes place. Thus it can be assumed that this damage is caused by humans.

The coral species suffering the highest amount of damage relative to their numerical presence, namely *Acropora*, *Millepora* and *Stylophora* species, are often dominant in the shallow areas of the reefs (Loya, 1972; Riegl, 1989). They are relatively fast growing and hence to a certain extent can tolerate repeated breakage (Highsmith, 1982; Rinkevich & Loya, 1983). This implies that the high human induced breakage on frequently visited reefs need not necessarily have adverse effects on communities consisting mainly of these species. Corals adapted to breakage are known to regenerate or reattach. If they die, free settling space for other species becomes available (Loya, 1976). By repeated anchoring, however, the reef crest's carbonate rock basis itself is broken, leading to the formation of loose boulders. This unstable material does not offer a good settling substrate for planulae (Alino *et al.*, 1985) and renders coral reattachment difficult. A marked reduction of living coral coverage and no signs of regeneration or increased settlement were observed on reefs used frequently for anchoring. This leads to the assumption that these damaged reef areas may remain unsuitable for resettlement for extended periods (as observed on Giftun saghir and Patch Reefs). Thus, reef damage through breakage is not only restricted to coral colonies. Reef rock is also affected, leading to partial reduction of substrates suitable for recolonization.

The reasons for tissue loss could not be assessed. Only in some cases could tissue loss be explained by predation (*Acanthaster planci* on tabular *Acropora* at Giftun saghir and Shaab Abu Rimathi) or by Black Band Disease (at 3 localities on 5 colonies of *Podabacia crustacea* and *Pachyseris speciosa*). The fact that minor tissue loss is more common than major tissue loss may be due to the regenerative abilities of the corals (Fishelson, 1973a). If corals were not able to stop the progression of tissue loss, as in the Band Diseases (Antonius, 1985), the amount of major tissue loss, indicated by moribund corals, should be greater than that of minor tissue loss. We observed a significantly higher frequency of minor tissue loss on reefs with high visitor frequency, which may indicate that this damage is human induced.

Algal overgrowth can often be considered as a secondary damage syndrome as it is known that algae readily colonize dead parts of coral colonies (Fishelson, 1973a; Benayahu & Loya, 1977; Walker & Ormond, 1982). However, algae are also able to overgrow living coral tissue

(Fishelson, 1973b). The high algal overgrowth on living and dead corals on the fringing reef in Hurghada may be caused by waste discharge and additional sediment input due to land reclamation and building activities in the lagoon. As the reef lies to the south of Hurghada, in the course of wind induced southerly currents, it is most certainly affected by pollutants from urban Hurghada. The as yet unquantified waste discharge and the additional stress caused by large amounts of sediment in the water may weaken the corals and could explain the high occurrence of algal overgrowth. Dense algal overgrowth of living tissue may lead to its death (Fishelson, 1973b).

The high algal overgrowth at Shaab Rur umm Qamar, an offshore platform reef, which is most certainly not affected by waste discharges from Hurghada, may be due to the high proportion of corals broken or suffering tissue loss on this reef. It is a popular diving spot due to the large fish which frequent the area. On Shaab Rur umm Qamar, numerous broken and overturned colonies provide substrates for turf algae. Broken corals, and especially those affected by tissue loss, are readily affected by algal overgrowth.

The most frequently overgrown corals (*Acropora*, *Pocillopora*, *Stylophora*, *Seriatopora*) were the branching ones. In Israel and Egypt the genus *Acropora* had the most algal overgrowth. This may in part be caused by the fact that the species of this genus are very common and proportionally more often affected by tissue loss and breakage, their damaged surfaces offering substrates for fouling algae. In this context, our observations agree with those of Fishelson (1973a), stating that branching forms with small corallites (such as *Acropora*) have less tissue regenerative abilities than massive forms with large corallites.

Considering the results of both the quantitative study and qualitative observations, it is concluded that even though clear damage allocation to specific causes is difficult, it seems that human induced damage is concentrated in the shallow regions such as the reef flat and the reef edge. Since this is also the region where natural physical stress due to wind, waves and exposure to air during low tides is most pronounced, some localities show signs of degradation including both coral damage and the destruction of the fossil reef basis. The design and application of specific reef management programs should be considered in order to avoid further damage and allow recovery of highly frequented reef sites.

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